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Development of a Framework for Multimodal Research: Creation of a Bibliographic Database

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14. ABSTRACT

The purpose of this report is to describe the development of a framework to enable classification, evaluation, and comparison of multimodal display research, based on task demands, display characteristics, research design, and individual differences. In this report, we describe the process by which a bibliographic database was developed and organized. First, the framework was specified, which then guided the identification and review of research and theory-based articles that were included in the bibliography. The results of the overall effort, the multimodal framework and article tracking sheet, bibliographic database, and searchable multimodal database make substantial and valuable contributions to the accumulation and interpretation of multimodal research. References collected in this effort are listed in the appendix.

15. SUBJECT TERMS

bibliography; literature review; multimodal; multi-task; tactile

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1. Introduction

Present-day Soldiers receive an unprecedented information flow from numerous sources in order to execute network-centric warfare. Such information overload can result in extremely high cognitive workload, which can subsequently reduce situational awareness and lower the quality of performance. This problem can be conceptualized as a multi-tasking issue or merely as a processing limitation. Consequently, information providers are challenged with identifying ways to disseminate and convey information as efficiently as possible so that a Soldier's comprehension and decision making are optimized, while overload and distraction are minimized.

A promising conceptual framework for the information overload problem is Wickens' (2002) Multiple Resource Theory (MRT). The premise of MRT is that different resources exist for processing different modalities of input (i.e., different cognitive resources exist for processing visual, audio, and tactile information). Therefore, when information is presented from different modalities, the performance decrement attributable to information overload should be smaller than when information is presented from a single modality to communicate the same amount of information. Simply stated, MRT proposes that (a) people have several independent capacities with resource properties; (b) some resources can be more easily used in tandem, while other combinations are more difficult and would be performed more sequentially; (c) tasks using compatible resources can usually be performed together; and (d) competition for the same sensory modality can produce interference. MRT explicates these capacities and contingencies (Wickens, 2002).

As an example, until recently, Soldiers received information primarily through visual presentation (map, compass, computer screen). When a large amount of information is presented solely through the visual modality, cognitive overload becomes problematic and can have negative effects on performance. MRT advises reducing the volume of information presented in one mode (visually) by offloading to one or more other modes (e.g., audio, tactile modes).

Numerous researchers have approached the information overload problem with MRT as the theoretical rationale (explicitly or implicitly) for using multiple modes of presentation to reduce workload (Wickens, 2002). In order to benefit from the vast amount of research on this topic, the research needs to be accumulated and classified on multiple dimensions such as the type of task and the demands associated with their use. Organization of the multimodal literature is warranted to support the application of research findings to display design. There is interest in determining the extent to which type of display modality can explain variance in performance and impact the use of cognitive resources.

The purpose of this research was to develop a framework to enable classification, evaluation, and comparison of multimodal display research based on task demands, display characteristics, research design and individual differences. In this report, we describe the process by which a bibliographic database was developed and organized. First the framework was specified, which then guided the

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2. Method

Elliott and Redden (personal communication, 2005) developed a framework to organize investigation and research experiments. This initial framework was refined and augmented by the research group at University of South Florida (Coovert, Gray, Elliott, Redden, 2006). The resulting multimodal framework represents the culmination of an extensive dialogue between the multimodal literature and the preliminary framework. The following sections describe the development of the multimodal framework and development of the multimodal database.

2.1 Development of the Framework

The multimodal framework (2005) (see figure 1) was a preliminary step to understanding the research on multimodal information processing. The use of the initial framework in reviewing research articles required deliberate consideration and consistent description of several study characteristics. The first step was to examine each of the initial framework components for inclusion in the multimodal framework (see figure 1 for original components). It was determined that the framework could benefit from further development to make it more comprehensive (new components to address research design, theory, results, conclusions, and coding of variables for meta-analytic purposes), as well as from modifications of the existing components to improve clarity and focus. The revised multimodal framework was developed to accommodate additional components in the form of the article tracking sheet (see figure 2).

Since the multimodal framework was intended to guide the review of research literature, we decided that the format should be conducive to the review of an article. The initial framework (see figure 1) existed as an electronic spreadsheet (columns were com-ponents, rows were research studies), whereas the article tracking sheet took the form of a five-page Word[1] document, designed to accompany a research article. The article tracking sheet encompassed some of the initial, several modified, and some new framework component fields, which were based on a preliminary literature review.

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[1]Word is a trademark of Microsoft Corporation.

2005 SU STO Synopsis
Green: Effect of 2nd Task on Primary Task Performance
Blue = Single ONE-Channel Display Comarisons re Primary Task, (comparison within one channel)
Orange = Single Other-Channel Display Comparisons re Primary Task: (compare different channels)
Yellow= Single Other-Channel Display Comparison re Secondary task (compare different channels)
Pink - Multi-modal Display comparison re Primary Task (combine different channels)

				1st TASK INPUT MODE					2ND TASK INPUT MODE				DISPLAY MANIPULATION			SINGLE OFFLOAD		MULTI-MODE	
																PRIM	2ND	SINGL	DIFF
DISPLAY	DONE	ROLE	PRIMARY/1ST TASK	VIS	AUD	COG	PHYS	2ND TASK	V	A	COG	PHY	VISUAL	AUDIO	TACTILE	TASK	TASK	TASK	TASKS
TACTILE LAND NAV (elliott)	Yes	DISMOUNT	NAVIGATION	X		X	X	COMMUNICATION	X	X	X		X (GPS; COMPASS)		X	X			
TACTILE LAND NAV 2 (elliott)	NO	DISMOUNT	TARGET DETECTION	X		X		NAVIGATION	X	X	X	X	X (HMD; GPS)		X		X		
TARGET ACQUISITION (glumm)	Yes	ICV Gunner	TARGET ACQUISITION	X		X		COMMUNICATION	X	X	X		X (CUE)	X (CUE) 3D AUDIO;SPEECH		X			
TARGET ACQUISITION 2 (glumm)	NO	ICV Gunner	TARGET ACQUISITION	X		X		MATH	X	X	X		X (CUE)	X(CUE) 3D AUDIO ;SPEECH		X		X	
C3 ALERTS (krausman)	NO	MOUNT PL ICV	MOVEMENT TO TARGET/SHOOTING	X	X	X							X (ALERT)	X (ALERT)	X (ALERT)	X			
C3 ALERTS 2 (krausman)	NO	MOUNT PL ICV	MOVEMENT TO TARGET/SHOOTING	X	X	X							X (ALERT)	X (ALERT)	X (ALERT)			X	
MCS SYSTEM (davis)	Yes	MOUNT	MOVEMENT TO TARGET/SHOOTING	X	?	X													
MCS INFO DISPLAY & SOLDIER DM (davis)	NO	MOUNT MCS	MOVEMENT TO TARGET/SHOOTING	X	?	X													
INFO DISPLAY for MOUNTED NAVIGATION (zuda)	?	MOUNT	MOVEMENT TO TARGE/NAVIGATION	X	?	X									X	X			
VISUAL WKLD - SHOOTING (scribner etal)	Yes	DISMOUNT	TARGET ACQUISITION	X	?	X		VISUAL	X				x				X		
INFO DISPLAY/MGT (willey)	?	C3: TL, 3 Riflemen,UA	C3 DECISIONS	X	?	X		MONITORING	X				X(COP); INFO-MGR;UAV			X			
ICON COMPLEXITY (mahan)	Yes	GENERAL/ALL	NAVIGATION ESTIMATION	X		X							Different Types			X			

Figure 1. Initial framework (Elliott & Redden, 2005).

Multimodal Typology: Article Tracking Sheet

Researcher_____   Today's Date_____

Article Title_____

_____

Article Authors_____

In what country was the study conducted?_____

What is the publication type?

_____Journal Article   _____Tech Report   _____Dissertation   _____Unpublished Work

_____Conference Proceedings   _____Book Chapter   _____Other_____

Are multiple studies described?   _____Yes   _____No

What is the study type?

_____Lab Experiment   _____Field Study   _____Literature Review

_____Theory   _____Evaluation Study   _____Other_____

Research Problem (What question is the study trying to answer? What is the goal of the study?)

_____

_____

_____

_____

_____

_____

Is the study related to **virtual reality**?   _____Yes   _____No

What is the theoretical basis of the study?

_____None   _____Wickens' MRT   _____Multiple theories   _____Other

If theoretical basis is "other," "multiple," or requires more information, elaborate:_____

_____

What are the IVs?_____

_____

What are the DVs? (ex. Number of errors, decision making time, subjective cognitive load, etc?)_____

_____

Figure 2. Article tracking sheet.

What is the secondary task being investigated, if applicable (ex: navigation, target detection, etc)?___

Does the secondary task involve:

Visual demands? ___Yes ___No ___N/A
Audio demands? ___Yes ___No ___N/A
Cognitive demands? ___Yes ___No ___N/A
Physical demands? ___Yes ___No ___N/A

Is it a comparison study, and if so, what type (**if more than one, check multiple and then explain**)?

___No

___Mode v. Mode (comparing an audio display to a visual display on the same task; or comparing the traditional mode to an alternative mode)

___Mode v. Multimode (comparing use of one mode to use of multiple modes)

___Multimodal Soldier's Choice (different modes available and soldier can choose which one he/she wants)

___Mode Across Situation (comparing use of audio display for one task to use of audio display for a different task)

___Multiple

___Other

If it's a comparison study, elaborate on what was compared (specific type of audio, etc)___

Is the device of interest providing the primary source of information, or augmenting other information for the **primary task?**

___Primary ___Augmenting ___Both ___N/A

Elaborate on above question including any conditional circumstances (if augmenting, is augmented info **redundant or different**)?___

Is the device of interest providing the primary source of information, or augmenting other information for the **secondary task?**

___Primary ___Augmenting ___Both ___N/A

How are the DVs operationalized? (Any scales used? Reliability of scales? Number of items used?)___

Describe the study design (was there a control group, what are the conditions, etc):___

What was the timeframe of the study?

___Predictive ___Concurrent ___Both ___N/A

What type of participants was used?

___Students ___Military ___Related Fields (ex. pilots)
___General Population (Adults) ___Other___

What was the sample size?___

Summarize the article findings:___

What types of statistics (means, SDs, F-tests, etc) or effect sizes are provided, and what pages are they on?___

What is the role of the device user (ex. dismount, ICV gunner, crew)___

What is the primary task being investigated (ex. navigation, target detection, etc)?___

Does the primary task involve:

Visual demands? ___Yes ___No ___N/A
Audio demands? ___Yes ___No ___N/A
Cognitive demands? ___Yes ___No ___N/A
Physical demands? ___Yes ___No ___N/A

Figure 2 (continued).

Elaborate on above question including any conditional circumstances (if augmenting, is augmented info redundant or different?): _____

Is the device offloading information for the **primary task?** _____ Yes _____ No

Is the device offloading information for the **secondary task?** _____ Yes _____ No

Is the device of interest:

Visual? _____ Yes _____ No   If yes, elaborate: _____
Audio? _____ Yes _____ No   If yes, elaborate: _____
Tactile? _____ Yes _____ No   If yes, elaborate: _____
Other? _____ Yes _____ No   If yes, elaborate: _____

Notes/Describe other devices that are being used for comparison _____

Are multiple modes of input from a device/devices being utilized simultaneously for the same task?
_____ Yes _____ No

Are multiple modes of input from a device/devices being utilized for different tasks?
_____ Yes _____ No

Does the article address the extent to which the device reduces the need to train to the point of automaticity? *(Or is it is relevant to automaticity?)* _____ Yes _____ No

Notes on relevance to automaticity, if applicable: _____

Is data fusion or information fusion mentioned? _____ Yes _____ No

Is situational awareness mentioned or relevant? _____ Yes _____ No

Does the article quantify task demand/conflict/interference values or mention **IMPRINT?**
_____ Yes _____ No

Notes on relevance to **IMPRINT**, if applicable: _____

Is the article relevant to Wickens' **MRT?** _____ Yes _____ No

Notes on relevance to Wickens' MRT, including any **deficiencies** (important material that can't be explained by Wickens' theory): _____

Does the article address any **individual differences** (ex: in learning styles, experience, training, age, gender, etc)? _____ Yes _____ No

What individual differences are addressed, and how do they tie in? _____

Is the research completed? _____ Yes _____ No _____ N/A

Describe any relevant notes on the rigor of the study, and if there are any major flaws to note: _____

What official keywords are reported by the article authors? _____

What other keywords do you think describe this article? _____

Guiding Principle Notes (ideas for possible guiding principles, take-home messages to keep track of, etc)
_____

Other General Notes _____

Figure 2 (continued).

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2.2 Literature Review

In an effort to locate articles spanning a variety of research domains, databases employed for the literature search included ACM (Association for Computing Machinery; http://www.acm.org/), IEEE (Institute of Electrical and Electronics Engineers; http://www.ieee.org/portal/site), PsycInfo (http://www.apa.org/psycinfo/), Web of Science (http://scientific.thomson.com/products/wos/), DTIC (Defense Technical Information Center; http://www.dtic.mil/), and CSA (http://www.csa.com/). A number of keywords were applied to each database to define the searches (e.g., multimodal, visual, tactile, audio, haptic, interface, display, dual task, multitask). The abstracts of articles returned by the databases were examined, and approximately 900 references that were initially deemed relevant were loaded into an on-line bibliographic management software (www.Refworks.com) for review. These references are listed in appendix A. Readers wishing to import references into their own Refworks or other bibliographic management software can contact the ARL point of contact (Dr. Elizabeth Redden) or Dr Michael Coovert, University of South Florida, to request an import file.

2.3 Cognitive Theory Objectives

One of the objectives for the literature review was to identify and review articles regarding theory of multitasking and multiple resources. Wicken's MRT served as a foundation for the multimodal framework, and therefore, articles that discussed or tested MRT concepts were coded specifically for easy retrieval. In addition, it was critical to remain familiar with other related cognitive issues; thus, a cognitive subcommittee of project members was formed. The subcommittee members reviewed literature (mentioned in previous section), which addressed cognitive issues more directly, and they provided summaries and presentations to the other project members during the literature review. As the review progressed, the committee noted that some important issues were not adequately addressed by Wickens' MRT (or any other theory). Although an in-depth analysis and application of these "deeper issues" was outside the scope of the present project, several topics were examined in more detail: parallel versus serial processing; individual differences such as user preferences and brain hemisphere dominance; automaticity; and cross-modal links. These four examples have considerable theoretical potential to interact with the relationship between multimodal information display and user performance. Therefore, they offer interesting directions for future research, especially regarding their integration with the predictions of Wickens' MRT.

2.4 Multimodal Database

Although the new article tracking sheet was useful for understanding the literature and coding articles according to the multimodal framework, the paper format was not conducive to queries or comparison of components across articles. Consequently, an Access[2] database was developed to provide an electronic version of the article tracking sheets for reviewed articles.

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[2]Access is a registered trademark of Microsoft Corporation.

Approximately 450 articles were reviewed and the respective article tracking sheets were entered into the database for each. The multimodal database includes all components present on the article tracking sheet. It supports queries, sorting, and filters as well as side-by-side comparison of studies or experiments for all multimodal framework fields. Furthermore, because of its versatile features, the database is essentially capable of answering multimodal research questions, such as

1. What mode of information display works best for driving?

2. Regarding alerts or interruptions, are multimodal displays better than unimodal displays?

3. Is there general support for Wickens' MRT?

The multimodal database is an Access-based deliverable that can be made available upon request to the ARL advanced objective manager (Dr Elizabeth Redden).

3. Implications, Applications, and Future Directions

The primary purpose of this research was to develop a framework to enable classification, evaluation, and comparison of multimodal display research based on task demands, display characteristics, research design, and individual differences. The identification of guiding principles for the design of multimodal information display was the second objective and is described in a separate report. The results of this effort, the multimodal framework and article tracking sheet, bibliographic database, and searchable multimodal database make substantial and valuable contributions to the accumulation and interpretation of multimodal research. References collected in this effort are listed in appendix A.

Possibly the most urgent future direction to address is the inconsistent use of terms in the multimodal literature. The most obvious nuisance involves the labeling of modalities. For instance, a number of articles do not consider a display to have a "visual modality" if the visual information exists in the natural environment. Other research operates on the premise that if visual cognitive resources are used to process information, then the term "visual modality" is appropriate, regardless of whether the information is displayed on a device or in the natural environment. This simple distinction presents a considerable obstacle to the formation of a knowledge base for the effects of multi-modal or unimodal displays where the "visual" modality is involved. A number of other critical terms are also used inconsistently (e.g., "multimodal" and "augment"), presumably because of the variety of research domains across which multimodal research takes place (e.g., human-computer interaction, psychology, engineering). A concerted effort to amass a glossary of multimodal and display design terms would offer a significant contribution toward improving the consistency of future research.

Another crucial objective for multimodal research is to complement the present qualitative effort with a quantitative examination of the effects of display modality on human performance. There are a number of important multimodal research questions worthy of meta-analysis, and their evaluation would not only offer empirical support for the guiding principles, but it would also reveal meaningful directions for future research.

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